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Experimental Study and the Effect of Alkali Treatment with Time on Jute Polyester Composites

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ABSTRACT:
The main aim of the work is the treatment that is to be given to enhance the surface properties of the fibers in view of obtaining better interfacial reaction between the matrix and the fiber of the composite, which in turn enhances the mechanical properties of the laminate on the whole. The work also focuses on the effect of alkaline solution treatment on the fibers. Numbers of laminates are prepared with different soaking time to be able to subject them to various test methods.
***Key words**: Alkali treatment, Natural fiber, laminate*

INTRODUCTION

Currently, many research projects are devoted to the utilization of cellulose-based fibers as reinforcement for plastics. However, these fibers are mainly composed of cellulose, hemi- cellulose, and lignin. In order to expand the use of cellulose-based fibers for composites, it is useful to have the information on fiber characteristics and factors which affect performance of the fibers

P. J. Roe, M. P. Ansell in (1985),[1] studied the behavior of the jute fiber. Raw jute fiber has been incorporated in a polyester resin matrix to form uni-axially reinforced composites containing up to 60 vol % fiber. The tensile strength and Young's modulus, work of fracture determined by Charpy impact and inter-laminar shear strength have been measured as a function of fiber volume fraction. Derived fiber strength and Young's modulus were calculated. Polyester resin forms an intimate bond with jute fibers up to a volume fraction of 0.6, above which the quantity of resin is insufficient to wet fibers completely. He compared properties of jute and glass fibers, and on a weight and cost basis jute fibers are seen in many respects to be superior to glass fibers as a composite reinforcement. Jute fiber forms an intimate bond with polyester resin, and can fully or partially replace glass fiber without entailing the introduction of new techniques of composite fabrication.

A.K. Mohanty, Mubarak A. Khan, G. Hinrichsen in (1998),[2] investigated on surface modifications of two varieties of jute fabrics, i.e. hessian cloth (HC) and carpet backing cloth (CBC), involving de waxing, alkali treatment, cyanoethylation and grafting, were made with a view to their use as reinforcing agents in composites based on a biodegradable polymeric matrix,

Dipa Ray, B.K.Sarkar, A.K.Rana and N.R .Bose in (2001),[3] investigated the effect of alkali treatment of 5% alkali (Noah) solution for 0, 2, 4, 6 and 8 h at 30°C.

Joung-Man Park, Son Tran Quang, Byung-Sun Hwang, K. Lawrence De Vries in (2005),[4] investigated on interfacial evaluation of the untreated and treated Jute and Hemp fibers reinforced different matrix polypropylene-maleic anhydride polypropylene copolymer (PP-MAPP) composites by micromechanical technique combined with acoustic emission (AE) and dynamic contact angle measurement.

Thi-Thu-Loan Doan, Hanna Brodowsky Edith Mader in (2006),[5] studied the thermal, dynamic mechanical and aging behavior are critical issues for the application of jute/polypropylene composites.

H.M.M.A. Rushed, M. A. Islam and F. B. Rizvi in (2006),[6] experimented on natural fibers such as flax, hemp, jute, kenaf. In the research work, jute fiber reinforced polypropylene matrix composites were developed by hot compression molding technique with varying process parameters, such as fiber condition (untreated and alkali treated), fiber sizes (1, 2 and 4 mm) and percentages (5%, 10% and 15% by weight).

An attempt was made by U. S. Ishiakul, X. Y. Yang, Y.W. Leong, H. Hamada, T. Semba, and K. Kitagawa in (2007),[7] at increasing both toughness and rigidity by simultaneous toughening and reinforcement.

X. Y. Liu and G. C. Dai in (2007),[8] reported about a new treating method using sodium hydroxide (Noah) and Maleic anhydride-grafted polypropylene (MPP) emulsion to treat jute fiber mat in order to enhance the performance of jute/polypropylene (PP) composite prepared by film stacking method. E. Sinha1,S.K. Rout P.K. Barhai in (2007),[9] all together treated the jute fibers with argon cold plasma for 5, 10 and 15 min. Structural macromolecular parameters of untreated and plasma treated fibers were investigated using small angle X-ray scattering (SAXS), and the crystallinity parameters of the same fibers were determined by using X-ray diffraction (XRD). K. Sabeel Ahmed, S. Vijayaranga in (2008),[10] investigated on the effect of stacking sequence on tensile, flexural and inter laminar shear properties of untreated woven jute and glass fabric reinforced polyester hybrid composites experimentally.

I. METHODOLOGY

A. Materials and Methods

The materials used in this work are: Jute Fibers, Sodium Hydroxide (Noah), Polyester Resin, Methyl ethyl ketone peroxide (MEKP)(used as catalyst) commonly called Hardener (K6).

B. Pre Treatment

A bunch of the clean fibers was taken to investigate the effect of time of alkali treatment on the weight of the fiber for each treatment time. After soaking the fibers for 8, 16 and 24 hours in alkali solution the weight of the fibers were recorded using the electronic balance.



Fig.1. Pretreatment (Alkali Noah) of the fibers





Fig.2. Weight of the fiber

The Jute fibers bags were washed with water to remove the contaminants and adhering dirt and were soaked in water for 48h. Thereafter, they were air dried at room temperature. After the jute fibers were completely dried the fibers were soaked in 10% Noah solution at ambient temperature and were air dried thoroughly at room temperature without destroying the fibrils. The jute bags after the treatment were cut into layers of 300mm x 300mm to make the laminates.



Fig.3. Pretreatment (Alkali Noah) of the fibers and the jute material

C. Testing of Specimens

Tensile test:

The tensile test is generally performed on flat specimens. During the test a uni-axial load is applied through both the ends of the specimen. The ASTM standard test method for tensile properties of fiber resin composites has the designation D 3039-76. The length of the test section is 120 mm approximately. The tensile test is performed in the universal testing machine (UTM) 1195 and results are analyzed to calculate the tensile strength of composite samples.





Fig.4. Specimen under tensile test

Flexural Test:

The short beam shear (SBS) tests are performed on the composite samples at room temperature to evaluate the value of flexural strength (FS). It is a 3-point bend test, which generally promotes failure by inter-laminar shear. The SBS test is conducted as per ASTM standard (D2344- 84) using the same UTM. Span length of 21 mm was maintained. The flexural strength (F.S.) of any composite specimen is determined using the following equation.





Fig.5.Specimen under the 3 point bending test

The equation to calculate flexural strength is, $F.S = \frac{3PL}{2bt^2}$

Where P is the load applied, L is the span length, b is the width and t is the thickness of the specimen.

Impact Test:

Un-notched Izod impact test was carried on the specimens with the required dimensions of the different fiber treatments and the fracture toughness values were recorded.

The test is a low velocity impact test.

I = K/A , where K is the energy absorbed and A is the area and values were recorded in J/cm^2

D. Equations for the evaluation of the experimental results:

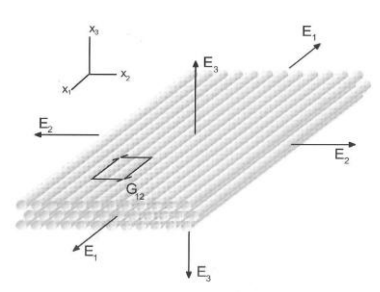


Fig.6. Representation of the Elastic properties of the composite laminate

According to Rule of mixtures assuming no voids in the composite laminate $V_f + V_m = 1$

Where V_f is volume fraction of the fiber, V_m is the volume fraction of the matrix. $V_f = \frac{\rho_m w_f}{\rho_f w_m + \rho_m w_f}$

Where V_f is the volume fraction of the fiber, ρ_m is the density of the matrix, ρ_f is the density of the fiber, w_f of the fiber, w_m is the weight of the matrix. $\sigma_c = \sigma_f V_f + \sigma_m V_m$

Where σ_c The tensile strength of the composite, σ_f is the tensile strength of the fiber, σ_m is the tensile strength of the matrix. $E_c = E_m V_m + E_f V_f$

Where E_c is the Young's modulus of the composite, E_m is the Young's modulus of the matrix, E_f is the Young's modulus of the fiber, V_m is the volume fraction of the matrix, V_f is volume fraction of the fiber.

Elastic properties of Orthotropic Lamina:

The number of independent elastic constraints required to characterize anisotropic and orthotropic materials are 21 and 9 respectively. For an orthotropic material, the 9 independent elastic constants are E_{11}, E_{22}, E_{33}, G_{12}, G_{13}, G_{23}, ϑ_{12}, ϑ_{13}, and ϑ_{23}

Elastic properties of the continuous fiber lamina are calculated from the following equations:

Longitudinal Modulus:, $E_{11} = E_f V_f + E_m V_m$

And Major Poisson's ratio by the formula, $\vartheta_{12} = E_f \vartheta_f + V_m \vartheta_m$

The Transverse modulus is calculated by the formula,

$$E_{22} = \frac{E_f (E_f V_m + E_m V_f)}{E_m}$$

Minor Poisson's ratio is calculated by the formula, $\vartheta_{21} = \frac{E_{22}}{E_{11}} \vartheta_{12}$

Shear modulus is calculated by the formula, $G_{12} = G_f V_m + G_m V_f$

The following properties are to be noted from the above equations

- The longitudinal modulus E_{11} is always greater than the transverse modulus E_{22}.
- The fiber contributes to the development of the longitudinal modulus, and the matrix contributes to the development of transverse modulus.
- The major Poisson's ratio ϑ_{12} is always greater than the minor Poisson's ratio ϑ_{21} .Since the Poisson's ratio is related by the equation only, can be considered independently.
- As in the case of E_{22}, the matrix contributes more to the development of G_{12} than the fibers
- Four independent elastic constants namely, E_{11}, E_{22}, ϑ_{12} and ϑ_{12} are required to describe the in plane elastic behavior of a lamina. The ratio E_{11}/E_{22} is often considered a measure of orthotropic.

The above equations are derived using the simple mechanics of the material approach along with the following assumptions.

- Both fibers and matrix are linearly elastic isotropic materials.
- Fibers are uniformly distributed in the matrix.
- Fibers are perfectly aligned
- There is perfect bonding between fibers and matrix
- The composite lamina is free of voids

Elastic isotropic lamina:

From the mechanics of materials the Cartesian strains resulting from a state of plane stress is represented by the following equations:

$$\sigma_z = \tau_{xz} = \tau_{yz} = 0, \qquad \varepsilon_x = \frac{1}{E(\sigma_x - \vartheta\sigma_y)},$$

$$\varepsilon_y = \frac{1}{E(\sigma_y - \vartheta\sigma_x)} ; \gamma_{xy} = \frac{1}{G\tau_{xy}}$$

In an isotropic material, considering plane stress, there is a strain also in z direction due to Poisson's effect, $\varepsilon_z = -\vartheta(\sigma_x + \sigma_y)$

This strain component will be ignored. In this relation there are three elastic components. These are Young's E, Poisson's ratio ϑ and shear modulus G$(\sigma_x = \tau_{xz} = \tau_{yz} = 0)$

$$\begin{Bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} \frac{1}{E} & \frac{\vartheta}{E} & 0 \\ \frac{-\vartheta}{E} & \frac{1}{E} & 0 \\ 0 & 0 & \frac{1}{G} \end{bmatrix} \begin{Bmatrix} \sigma_x \\ \sigma_y \\ \tau_{xy} \end{Bmatrix}$$

The stiffness matrix $[Q]$ can be formulated as follows $[S]$ represents the compliance matrix relating strains to known stresses. The inverse of the compliance matrix is called stiffness matrix, which is used in relating stresses and strains. Thus, the stiffness matrix $[Q]$ for an isotropic lamina is:

$$[Q] = [S^{-1}] = \begin{bmatrix} \frac{E}{1-\vartheta^2} & \frac{\vartheta E}{1-\vartheta^2} & 0 \\ \frac{\vartheta E}{1-\vartheta^2} & \frac{E}{1-\vartheta^2} & 0 \\ 0 & 0 & G \end{bmatrix}$$

Stiffness Matrix for orthotropic lamina:

In the same as above, by arranging equations in matrix form, the stress strain relation can be written as given below

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} S_{11} & S_{12} & 0 \\ S_{21} & S_{22} & 0 \\ 0 & 0 & S_{66} \end{bmatrix} \begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix} = [S] \begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix}$$

Where $S_{11} = \frac{1}{E_{11}}$

$$S_{12} = S_{21} = \frac{\vartheta_{12}}{E_{11}} = \frac{\vartheta_{21}}{E_{22}}, \quad S_{22} = \frac{1}{E_{22}}, \quad S_{66} = \frac{1}{G_{12}}$$

The $[S]$ matrix is called the compliance matrix for a special orthotropic lamina. Inverting the above equation we can write the stress strain relation for a special orthotropic lamina as:

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} Q_{11} & Q_{12} & 0 \\ Q_{21} & Q_{22} & 0 \\ 0 & 0 & Q_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} = [Q] \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix}$$

Where $[Q]$ represent he stiffness matrix for especially orthotropic lamina. Various elements in the $[Q]$ matrix are

$$[Q_{11}] = \frac{E_{11}}{(1-\vartheta_{12} * \vartheta_{21})}, \quad [Q_{22}] = \frac{E_{22}}{(1-\vartheta_{12} * \vartheta_{21})},$$

$$[Q_{12}] = [Q_{21}] = \frac{\vartheta_{12} E_{22}}{(1-\vartheta_{12} * \vartheta_{21})} = \frac{\vartheta_{21} E_{11}}{(1-\vartheta_{12} * \vartheta_{21})},$$

$$[Q_{66}] = G_{12}$$

General Stiffness Matrix for Orthotropic Lamina ($\theta \neq 0°$ or $90°$):

The Stress-Strain relation for a general orthotropic lamina can be expressed in the matrix notation as

$$\begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} = \begin{bmatrix} S'_{11} & S'_{12} & S'_{16} \\ S'_{21} & S'_{22} & S^{2}_{26} \\ S'_{16} & S'_{26} & S'_{66} \end{bmatrix} \begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix} = [S'] \begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix}$$

$$S'_{11} = \frac{1}{E_{xx}} = S_{11}\cos^4\theta + (2S_{11} + S_{66}) sin^2\theta cos^2\theta + S_{22} sin^4\theta,$$

$$S'_{22} = \frac{1}{E_{yy}} = S_{11} sin^4\theta + (2S_{12} + S_{66}) sin^2\theta cos^2\theta + S_{22} cos^4\theta$$

$$S'_{16} = -m_x = (2S_{11} - 2S_{12} - 2S_{66}) sin\theta cos^3\theta - (2S_{22} - S_{66}) sin\theta cos^3\theta$$

$$S'_{26} = -m_y = (2S_{11} - 2S_{12} - S_{66}) sin^3\theta cos^1\theta - (2S_{22} - 2S_{12} - S_{66}) sin^3\theta cos\theta,$$

$$S'_{66} = \frac{1}{G_{xy}} = 2(2S_{11} + 2S_{22} - 4S_{12} - S_{66}) sin^2\theta cos^2\theta + S_{66} sin^4\theta + cos^4\theta$$

On inverting the stress-strain relations for the general orthotropic lamina can be written as

$$\begin{Bmatrix} \sigma_{xx} \\ \sigma_{yy} \\ \tau_{xy} \end{Bmatrix} = \begin{bmatrix} Q'_{11} & Q'_{12} & Q'_{16} \\ Q'_{21} & Q'_{22} & Q'_{26} \\ Q'_{16} & Q'_{26} & Q'_{66} \end{bmatrix} \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix} = [Q'] \begin{Bmatrix} \varepsilon_{xx} \\ \varepsilon_{yy} \\ \gamma_{xy} \end{Bmatrix}$$

Where $[Q']$ represents the stiffness matrix for the lamina, various elements in $[Q']$ are expressed in terms of the elements in the $[Q]$ matrix as

$$\bar{Q}_{11} = Q_{11} cos^4\theta + Q_{22} sin^4\theta + (2Q_{12} + 4Q_{66}) cos^2\theta \, sin^2\theta,$$

$$\bar{Q}_{12} = (Q_{11} + Q_{22} - 4Q_{66}) cos^2\theta \, sin^2\theta + Q_{12}(cos^4\theta + sin^4\theta)$$

$$\bar{Q}_{22} = Q_{11} sin^4\theta + Q_{22} cos^4\theta + (2Q_{12} + 4Q_{66}) cos^2\theta \, sin^2\theta,$$

$$\bar{Q}_{66} = (Q_{11} + Q_{22} - 2Q_{12} - 2Q_{66}) cos^2\theta \, sin^2\theta + Q_{66}(cos^4\theta + sin^4\theta)$$

$$\bar{Q}_{16} = (Q_{11} - 2Q_{66} - Q_{12}) cos^3\theta sin\theta - (Q_{22} - Q_{12} - 2Q_{66}) cos\theta sin^3\theta,$$

$$\bar{Q}_{26} = (Q_{11} - 2Q_{66} - Q_{12}) \, cos\theta sin^3\theta - (Q_{22} - Q_{12} - 2Q_{66}) cos^3\theta sin\theta$$

From the above system of equations the following properties of the materials could be inferred.

Elements S_{16} and S_{26} in the $[S]$ matrix or Q_{16} and Q_{26} in the $[Q]$ matrix represent extension shear coupling.

- From the above equations it appears that there are 6 elastic constants that govern the stress- strain behavior of the lamina. However closer examinations of these equations indicate that S'_{16} and S'_{26} are linear combinations of four basic elastic constants, namely, S'_{11}, S'_{12}, S'_{22}, S'_{66} and therefore are not independent. Elements in both the $[S']$ and $[Q]$ matrices are expressed in terms of the properties in the principal material directions, namely, E_{11}, E_{22}, G_{12} ϑ_{12} which can either experimentally determined or predicted approximately from the constituent properties using the equations.

II. RESULTS AND DISCUSSION

Composite laminates have been prepared with the same volume fraction of the fiber for all the laminates and have been tested by cutting them into required dimensions to perform tests. All the tests have been performed on the specimens and results obtained from the experiments have been tabulated and graphed.

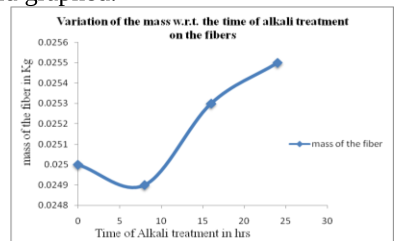


Fig.7. Time of Alkali treatment Vs Mass of the Fiber

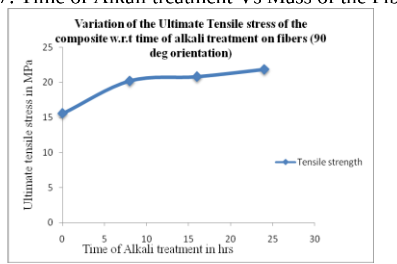


Fig.8. Ultimate stress of the composite (90 deg) Vs Time of alkali treatment

The fig 7 shows the change in the mass of the fiber with the change in the hours of treatment .In this graph we see that the there is a decrease in the fiber mass after 8 hours of alkali treatment and it increases after 24 hours of alkali treatment.

Tensile test:

The fig 8 gives the information that there is a very little change between 8 and 16 hours of treatment of the fiber; however there is a considerable change in the ultimate stress between 0 and 8 hours of alkali treatment.

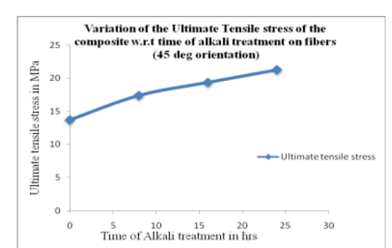


Fig.9.Stress of the composite (45 deg) Vs Time of alkali Treatment

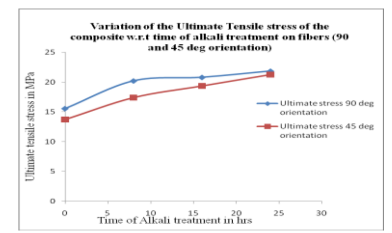


Fig.10.Ultimate stress of the composite (90 deg and 45 deg) Vs Time of alkali treatment

From the Fig.9 we can conclude that the there is a gradual change in the value of ultimate stress of the composite between 0 to 8, 8 to 16 and 16 to 24 hours of treatment which is unlike the change in 90 deg orientation of the composite. From the Fig.10.we can conclude that for all the time intervals of the treatments given to the fiber, the value of ultimate stress of the composite for 90 deg(blue curve) orientation of the fiber is higher when compared to 45 deg (red curve) orientation. And we can also see that both the curves converge at 24 hours of treatment of the fiber.

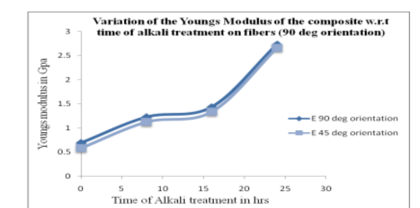


Fig.11. Young's Modulus Vs Time of alkali treatment

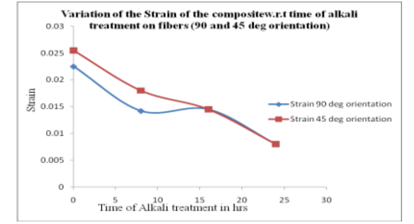


Fig.12. Strain of the composite Vs Time of alkali treatment

The Fig.11 shows the value of Young's modulus of the composite in the both orientations (90 deg and 45 deg). From the graph we can say that the Young's modulus for the both the orientations of the fiber in the composite at are almost equal.

From the Fig.12 it's clear that in composites of both the orientation of the fiber the strain increases as the time of alkali treatment increases. It is drastic in the 45 deg fiber oriented composite where as we do not see that in 90 deg fiber oriented composite and it does not follow a regular pattern

The flexural test and Impact test:

The fig 13 shows that the flexural strength of the composite w.r.t time of alkali treatment from 0 to 24 hours is increasing in 90 deg orientation of the fiber. Flexural strength value remains close between 8 hours and 16 hours of treatment of the fiber and then increase between 16 to 24 hours.

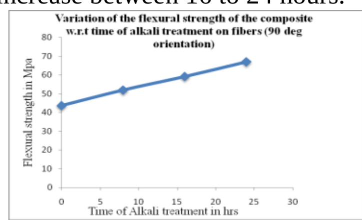


Fig.13. Flexural Strength Vs time of alkali treatment (90 deg Orientation)

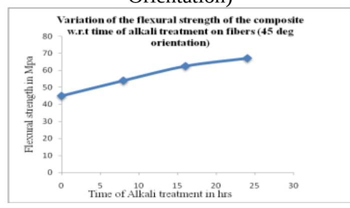


Fig.14. Flexural Strength Vs time of alkali treatment (45 deg Orientation)

The fig 14 shows the Flexural strength value remains close between 8 hours and 16 hours of treatment of the fiber and then increase between 16 to 24 hours of treatment of the fiber and there is also an increase seen between untreated and 8 hours of alkali treated fiber.

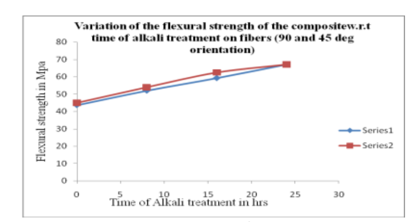


Fig.15. Flexural Strength Vs time of Alkali treatment (90and 45 deg)

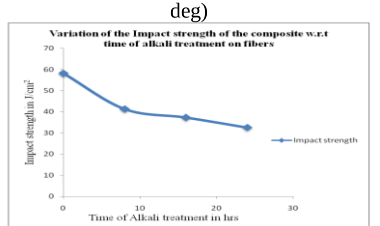


Fig.16. Impact Strength Vs time of Alkali treatment

From the fig 16 we see that the red curve by passes that blue one which means that the flexural strength at the 16 hours of treatment of the fiber in both orientations is same and the flexural strength is higher for the 45 deg orientation of the

fiber at 24 hours of fiber treatment than that in 90 deg orientation of the fiber.The above Figure Gives the information about the impact strength of the jute fiber composite between 0 to 24 hours of treatment .We see that the impact strength gradually decreases between untreated to the 24 hours treated jute fiber composite.

III. CONCLUSIONS

- The alkali treatment given to the fibers with the different time intervals first resulted in decrease in the weight of the fiber and then the weight increased between 16 hours of treatment and 24 hours of treatment.
- The initial decrease in the weight of the fiber could be attributed to the decrease in the hemicelluloses and lignin. The increase in weight after 16 hours of treatment could be because of the regain of the same contents as the fibers are treated for longer duration.
- Rougher surface area and increased surface area of the chemically treated fibers facilitated better interaction between the fiber and the matrix. Thus composite laminate prepared with the chemically modified fibers showed better tensile and flexural properties.
- The composite laminate prepared with the 16 hours alkali treated fibers can be used where weight of the of the material is of concern.
- There was a drop in the strain value between the laminates prepared with the untreated and the treated jute fiber which gives an indication that exposing the fibers to the alkali solution for longer duration could result in making the fibers brittle.
- It is observed that the impact strength of the laminates decreased with the increasing hours of alkali treatment of the fibers, which could be because of the strong fiber/matrix adhesion that hinders the energy absorption mechanisms, such as de-bonding and fiber pull out.
- Composites fabricated from the natural fiber can be used where they are subjected to lower values of loads as in house hold appliances.

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